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SIR HAROLD WALTER KROTO

7 October 1939 —30 April 2016

Elected FRS 1990

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EARLY LIFE, SCHOOL AND UNIVERSITY EDUCATION

Harold Walter Kroto was born on 7 October 1939 in Wisbech, Cambridgeshire in the UK. [He was always called 'Harold' by his parents and at school. It was not until his undergraduate days that he acquired the title 'Harry', by which he was later universally known.] Harry's parents were Heinz and Edith Krotoschiner (the family name was changed to Kroto in 1955). The story of how these two German nationals ended up in the UK is sadly familiar. Heinz and Edith lived in Berlin, where Heinz had been born in 1900, where he grew up and where he subsequently ran a business, the products of which were toy balloons with graphics printed on them. As a Jew, it was becoming increasingly uncomfortable for him to continue living in Berlin

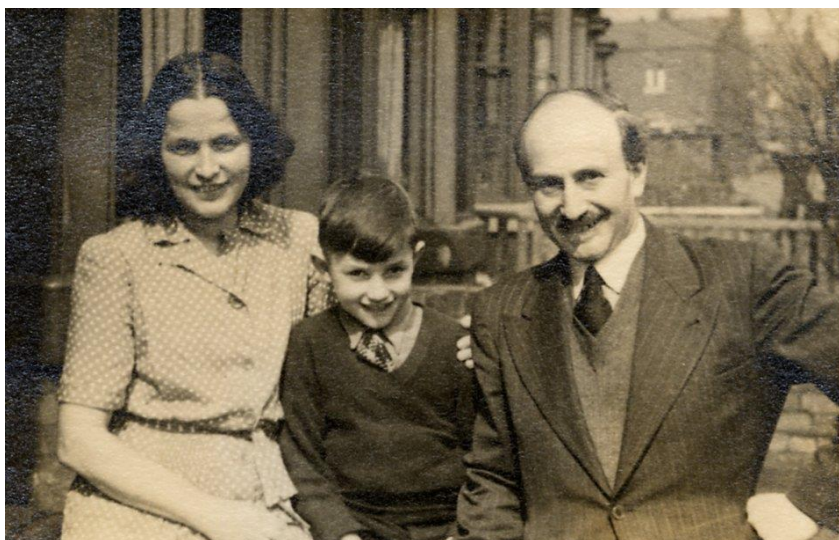


Figure 1 Edith and Heinz Krotoschiner with Harold, aged about 6 years old. (Copyright Margaret Kroto)

and so he abandoned his business and escaped, via Holland, to England in 1938. His wife joined him shortly afterwards. Initially, they lived in London and he attempted to start in the same line of business again, but at the outbreak of the Second World War Heinz was declared an enemy alien and was interned on the Isle of Man. He was released sometime before the end of the war. Harry's mother was evacuated to Wisbech in 1939 (where Harry was born), but moved back to London when Harry was three weeks old. In

1940, Harry's mother was given the choice of yet another move, either to Peterborough or Bolton. She chose Bolton, where Harry grew up and went to school. Harry has described himself as having '...a couple of somewhat eccentric parents (in particular an extrovertly gregarious mother)...' (http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/kroto-bio.html) It seems possible that Harry inherited these aspects of her personality.

After the war, Heinz Krotoschiner retrained, through an apprenticeship, and qualified as a toolmaker in a short time. He worked in that capacity for some years until, in 1955, he started yet again his own factory for making balloons and printing on them. Harry has acknowledged in his Nobel biography (http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/kroto-bio.html) that his work in many aspects of the family business during the school holidays was valuable training in problem-solving skills.

Harry was fortunate, as were many of his generation, that his schooling coincided with the period, ushered in by the 1944 Education Act, in which a high-quality, academic education was available even to the poorest (his parents had lost everything as a result of their move). Initially, he attended Wolfenden Street School in Bolton, but in 1947 transferred to Bolton School. Although Bolton School was at that time a Direct Grant School, he was able to win a scholarship, which ensured that his parents did not have to pay fees. He enjoyed his time (1947-1958) at Bolton School and developed wide interests, especially in graphic art (enthusiasm for which was a thread that ran throughout his life), geography, gymnastics and woodwork to begin with. As he approached the Sixth Form, however, he started to lean towards the sciences: chemistry, physics and mathematics. He also participated in the dramatic arts, as is illustrated by his



Figure 2. HWK as the Duke of York (third from left) and Ian McKellen (pointing) in the Bolton School production of Henry V. (Copyright Margaret Kroto)

appearance as the Duke of York in Shakespeare's Henry V, the title role in which was played by Ian McKellen who was in the same year at Bolton School and is now a world-famous and much-honoured actor (see Figure 2). Harry also developed as an athlete, played football and cricket and became an accomplished tennis player.

Chemistry was his favourite academic subject. He has written (http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/kroto-bio.html) that: 'I, like almost all chemists I know, was also attracted by the smells and bangs that endowed chemistry with that slight but charismatic element of danger' He was inspired by two Chemistry teachers he encountered at Bolton School. The first was Dr Wilf Jary, who impressed Harry with his experimental dexterity, and the second was Harry Heaney, later to become Professor of Organic Chemistry at Loughborough University. It was Heaney who advised Harry Kroto to follow a degree course in Chemistry at the University of Sheffield, which he considered to be have the best Chemistry Department in the UK at the time.

Harry arrived at the University of Sheffield at the age of 19 in October 1958. Despite having many extra-curricula interests (including playing in the University Tennis Team and acting as art editor of the student magazine 'Arrows', which also required him to design covers and posters) he obtained a BSc (First Class) degree in Chemistry in 1961. Originally, he had favoured organic chemistry (partly as a result of Heaney's influence) but during his undergraduate years his interests gravitated towards spectroscopy and quantum mechanics. He had the good fortune to be taught the former by Richard N Dixon (FRS 1986), subsequently Professor of Theoretical Chemistry at the University of Bristol, and the latter by John N Murrell (FRS 1991). Murrell was later to become Harry's close friend and colleague at the University of Sussex.

Harry began his doctoral research in October 1961, with Richard Dixon as his supervisor. Two publications (1,2) resulted from this period and both involved the production of small, short-lived molecules by the technique called flash photolysis, as developed by R. G. W. Norrish (FRS, 1936) and G. Porter (FRS, 1960) (Norrish & Porter 1949). In this approach, a highly energetic but short pulse of radiation (the flash) is fired into the vapour of a precursor substance (for example, bromoform HCBBr_3 in ref. (1)). Molecules of the precursor absorb the radiation and rapidly decompose to produce (usually) a short-lived radical (for example CBr in ref.(1)). After a short delay of ~ 10 microseconds, lower-powered radiation of an appropriate wavelength range is passed through the vessel containing the nascent radicals, allowing their electronic absorption spectrum to be photographed (in the case of CBr described in ref.(1), the electronic transition is $^2\Delta_{5/2} \leftarrow ^2\Pi_{3/2}$). As Harry pointed out in his Nobel Biography

(http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/kroto-bio.html), ‘George Porter was Professor of Physical Chemistry at Sheffield at the time, so there was a lot of flashing going on.’ Harry also had other calls on his time while he was carrying out his doctoral research. For example, he was President of the University Athletics Council and he represented the University at tennis. During that period he met his future wife, Margaret Hunter, who was reading Philosophy, Politics and Economics at the University. They married on 20 July 1963.



Figure 3 Harry and Margaret embark on *The Empress of Canada* at Liverpool in 1964, bound for Ottawa. (Copyright Margaret Kroto)

Towards the end of his PhD research in 1964, Harry was attracted by the prospect of post-doctoral work in North America. With the help of Richard Dixon, he was won a prestigious National Research Council of Canada Postdoctoral Fellowship in the world-famous molecular spectroscopy laboratory, headed by Alex E. Douglas (FRS, 1979), and housed within the Division of Pure Physics of the National Research Council in Ottawa (see Figure 3), which had Gerhard Herzberg (FRS, 1951) at the helm. Herzberg's contributions to molecular spectroscopy won him the Nobel Prize for Chemistry in 1971. Collected in the NRC, Ottawa at that time was a glittering array of talent, including Donald A. Ramsay (FRS, 1978), Cecil C. Costain, James K. G. Watson (FRS, 1987), Takeshi Oka (FRS, 1984) and Jon Hougen. Harry enjoyed the freedom given to him by Herzberg and Douglas to pursue whatever interested him. Initially, he worked in Don Ramsay's laboratory on the NCN radical (3,4) produced by the flash photolysis of cyanogen azide NCN_3 . Takeshi Oka, who had befriended and helped Harry and Margaret when they first arrived in Ottawa, was a

member of the Ramsay laboratory at that time and Harry's close scientific interaction with him cemented a lifelong friendship between them. Harry later became interested in the microwave spectroscopy being conducted in Cec Costain's laboratory and at the end of his first year in Ottawa he transferred to Costain's group. There he worked on the microwave spectrum of cyanogen azide (5). Harry learned much about quantum mechanics and spectroscopy from Jim Watson and Jon Hougen. The people he got to know at NRC had a strong influence on his intellectual development and his friendship with them lasted for the rest of his life. His admiration for Herzberg shines through the obituary he contributed to The Guardian newspaper (30 March 1999).

At the end of two years in Ottawa, in 1966, Harry moved to the USA to a post-doctoral position at Bell Telephone Laboratories, Murray Hill, New Jersey, where he worked on investigations of liquid phase interactions by laser Raman spectroscopy. After a year, it was time to return to the UK and begin his independent academic career at the recently-founded University of Sussex.

UNIVERSITY OF SUSSEX 1967-1985

At the invitation of John Murrell, who had moved from Sheffield to Sussex in 1965 as Professor of Chemistry, Harry accepted a Tutorial Fellowship in Chemistry at the University of Sussex at a salary greatly reduced from that he received at Murray Hill. With one child already (Stephen born in Ottawa in 1966)



Figure 4 Margaret Kroto with their two sons Stephen (left) and David (right). (Copyright Margaret Kroto).

and another on the way (David born in Brighton in 1968; see Figure 4)), the Krots considered returning to the USA but the conversion of the Sussex post to a Lectureship convinced them to stay. Harry remained at

Sussex until 2004, first as Lecturer from 1968-1977, then as Reader from 1977-1985, as Professor from 1985-1991 and finally as Royal Society Research Professor from 1991-2004.

Harry's publications in the period from 1967 until the discovery of C_{60} in 1985 reveal how his interests developed. The first papers published with the University of Sussex were essentially a continuation of his interests from his time in Ottawa and Bell Labs. The period between 1972 and 1985 was particularly productive, resulting in about 80 publications concerned with the synthesis and spectroscopy (mainly rotational and photoelectron spectroscopy) of small 'semi-stable' reactive molecules.

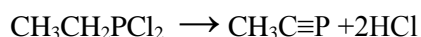
First, he became attracted by the possibility of producing, small, short-lived molecules by techniques such as pyrolysis and then characterizing them spectroscopically. Photoelectron spectroscopy provides detailed information about the electronic structure of a molecule, while microwave (rotational) spectroscopy can yield the order of the atoms (by isotopic substitution), precise molecular geometries, electric dipole moments, details of any internal rotational motion, and, in suitable cases, vibrational separations in the lowest energy modes of molecules. Initially, he concentrated on generating, from a range of precursors, unstable sulfur analogues of well-known oxygen-containing molecules such as carbon monoxide CO, acetaldehyde CH_3CHO , acetone $(CH_3)_2O$, formaldehyde H_2CO and ketene $CH_2=C=O$. Thus, for example, $CS(6)$, $H_2C=S$ (7) CH_3CHS and $(CH_3)_2CS$ (8), and $CH_2=C=S$ (9) were produced and characterized spectroscopically. Other hitherto unknown molecules were also identified by the pyrolysis technique and characterized spectroscopically. To give one example, the new linear molecule thioborane, ClBS, was generated by passing S_2Cl_2 over boron heated to 1000 °C and was characterized in detail by the two spectroscopic methods (21).

An excellent, full account of Harry's research strategy in connection with the many molecules he produced by pyrolysis is given in his Tilden Lecture in 1982 entitled 'Semi-stable molecules in the laboratory and in space' (26). During the early 1970s he wrote a well-received monograph on rotational spectroscopy, entitled '*Molecular Rotation Spectra*', published by Wiley in 1975 (10), which meant that he was on top of the theory of the subject.* The superb Hewlett-Packard 8460A microwave spectrometer, available in Sussex from the mid-1970's, had the novelty of semi-automatic frequency scanning of backward wave oscillators. This freed the operator from the fiddling task of manually adjusting klystron

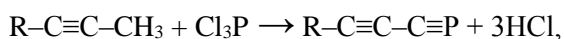
**Molecular Rotation Spectra* is a compact, but rigorously argued, monograph, written for spectroscopists from the viewpoint of modern quantum mechanical methods (including angular momentum operators, derivation of selection rules, and vibration-rotation interaction theory), as learned from Jon Hougen and James K G Watson while at NRC in Ottawa some ten years earlier. Harry was delighted when in 1992 it was republished by Dover, an honour reserved for classic texts. The preface includes numerous rotational spectra of small (and some very long) molecules, all recorded with a Hewlett-Packard 8460A microwave spectrometer. These spectra (all from his own research) illustrate the beauty and elegance of the subject.

dimensions, reflector voltage, etc. to generate radiation over a tiny frequency range and allowed him/her to concentrate on the difficult matter of getting the ‘semi-stable’ molecules into the waveguide cell. So he was well equipped theoretically and experimentally to make rapid progress with the detection and analysis of small unstable molecules.

From the sulfur (and selenium) analogues of familiar oxygen-containing organic compounds, Harry next turned his attention to phosphorus counterparts of simple nitrogen-containing compounds. These too were often generated by the pyrolysis of suitable precursors. In this project, he teamed up with his Sussex colleague John Nixon (FRS 1994), an expert in the synthesis and chemistry of phosphorus compounds. As a result of this collaboration, they produced a large number of P analogues of simple, familiar N-containing organic molecules and in the process discovered simple, general methods. Thus, $\text{CH}_3\text{C}\equiv\text{P}$, the analogue of methyl cyanide, was produced (11,18) by flow pyrolysis of the precursor $\text{CH}_3\text{CH}_2\text{PCl}_2$ from which HCl is eliminated.



This approach proved to be generally applicable (26), so that, by the pyrolysis of the appropriate precursor $\text{CH}_3\text{CX}_2\text{PY}_2$, it was possible to generate and fully characterize (by rotational and photoelectron spectroscopy) the family of phospha-alkynes $\text{CH}_3\text{C}\equiv\text{P}$ (11,18), $\text{FC}\equiv\text{P}$ (17, 20), $\text{CH}_2=\text{CH}-\text{C}\equiv\text{P}$ (24) and others. Precursors of the type $\text{R}-\text{C}\equiv\text{C}-\text{CH}_3$ allowed, for example, each of $\text{H}-\text{C}\equiv\text{C}-\text{C}\equiv\text{P}$ (25), and $\text{N}\equiv\text{C}-\text{C}\equiv\text{C}-\text{C}\equiv\text{P}$ (28) to be formed by the general pyrolysis route



with $\text{R} = \text{H}$ or CN . The corresponding reaction of methyl cyanide with phosphorus trichloride, namely



leads to cyano-phospha-alkyne (19), a P analogue of cyanogen. All three of these linear molecules were detected by means of their microwave rotational spectra.

Figure 5 shows a portion of the spectrum of $\text{CH}_3\text{C}\equiv\text{P}$ (26) recorded by means of the Hewlett-Packard 8460A microwave spectrometer. This instrument relied for its high sensitivity on the Stark effect, that is the effect of a uniform, static electric field of strength E on the rotational energy levels (and therefore transitions) of a molecule which as a result split into several components. Rapid switching of the electric field strength between 0 and E allows both the zero-field transition (upward pointing in Figure 5) and the

Stark components into which it splits at field strength E (downward point lobes) to be displayed. The detailed pattern of Stark components (intensities and shifts) of a given rotational transition is determined by the quantum numbers involved and often allows their relatively straight-forward assignment. The electric dipole moment of the molecule can be determined accurately by measuring the frequency shift of a given Stark component as a function of E . Figure 5 is a good example of why Harry derived much aesthetic pleasure from such spectra.

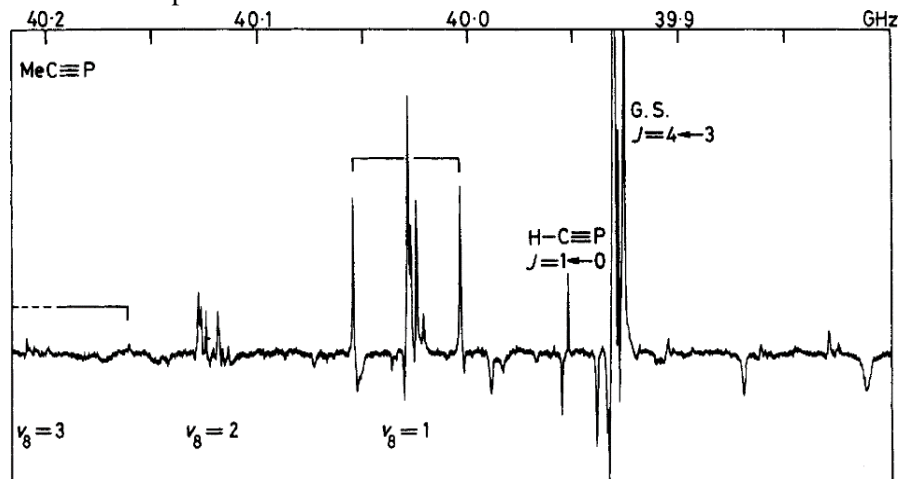
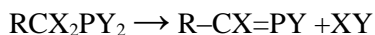


Figure 5. The $J = 4 \leftarrow 3$ transition of $\text{CH}_3\text{C}\equiv\text{P}$ recorded with a Hewlett-Packard 8460A microwave spectrometer. $\text{CH}_3\text{C}\equiv\text{P}$ was produced by pyrolysis of $\text{CH}_3\text{CH}_2\text{PCl}_2$, which loses two units of HCl to give the product. GS signifies the rotational transition in the vibrational ground state. Transitions $\nu_g = n$ are the same rotational transition in a vibrational state with n quanta of the lowest frequency bending mode excited. Upward-pointing transitions are at zero applied electric field strength and downward pointing lobes are the Stark effect (see text.) The $J = 1 \leftarrow 0$ transition of $\text{HC}\equiv\text{P}$ (with just one Stark component) is also present. (Reproduced from ref.(26) with permission of the Royal Society of Chemistry).

It was also possible to produce a whole family of phospho-alkenes $\text{R}-\text{CX}=\text{PY}$ by means of the pyrolysis of various types of precursor. A general method that was discovered (26) utilizes the precursor RCX_2PY_2 from which, on heating to a sufficient temperature, XY is eliminated to leave the phospho-alkene, according to



By using this route the phospho-alkenes $\text{CH}_2=\text{PH}$ (12, 23) and $\text{CH}_2=\text{PCl}$ (12, 27) were generated and then detected through their rotational spectra, to mention just two examples. $\text{CH}_2=\text{PH}$ was the first molecule carrying a carbon-phosphorus double bond to be synthesized (Harry said he got more intellectual satisfaction from this than from the discovery of C_{60}). The methods of production of all the phosph-alkynes

and phospho-alkenes mentioned here, and of various other $R-CX=PY$ not mentioned here, are fully described in the Tilden Lecture (26).

Harry also began a collaboration with his Sussex colleague, David Walton, in the mid-1970's, the aim of which was to synthesize linear molecules in the series of cyano-poly-ynes $H(C\equiv C)_n-C\equiv N$ and to examine their rotational spectra. David Walton had great expertise in the (potentially dangerous) field of poly-ynes synthesis and his contribution was very important. Long, linear molecules of this type have several low-lying bending modes of vibrations, excited states of which are well-populated at room temperature. Such molecules therefore exhibit in their rotational spectra rich vibrational satellite patterns (*i.e.* rotational transitions in vibrationally excited states of the bending vibrations). The main reason for the research initially appears to have been to provide a severe experimental test of the theory of vibration-rotation interaction in such linear molecules, with which Harry was familiar from the preparation of his monograph *Molecular Rotation Spectra* (10). The first molecule in the series to be prepared and its rotational spectrum observed was cyanobutadiyne, $H(C\equiv C)_2-C\equiv N$ (13), (sometimes called cyanodiacetylene) and it does indeed exhibit a beautiful pattern of bending vibrational satellites (see Figures 1 and 2 in ref. (13)). Interestingly, an undergraduate (Andrew Alexander), reading for the BSc by Thesis degree, was the student involved in the project. Harry was always a strong advocate of this type of degree.

Almost simultaneously, a search (suggested by Harry to Takeshi Oka, who enthusiastically took up the suggestion) was carried out with the Algonquin Park radio-telescope in Canada for the $J = 4 \rightarrow 3$ rotational transition of cyanobutadiyne in emission in the interstellar medium. Although this transition had not been observed directly in the laboratory, an accurate frequency was available from the ground-state rotational and centrifugal distortion constants reported in (13). The transition was quickly detected (14) in the interstellar cloud that lies in the direction of Sgr B2. This led Harry to speculate that, since cyanobutadiyne has two carbon atoms more than any molecule that had hitherto been detected in interstellar space, the molecular clouds in the direction of Sgr B2 must be rich in carbon-containing molecules. David Walton experienced more difficulty with the synthesis of the next member of the series $H(C\equiv C)_n-C\equiv N$, that having $n = 3$, but was eventually successful (22). Although the terrestrial rotational spectrum of HC_7N was detected, the date booked for making observations on the Algonquin telescope arrived just as the spectroscopic constants of this species were being measured in the laboratory. After some drama, involving a chain of telephone calls (a) from Colin Kirby, the research student working on HC_7N at Sussex, to Margaret Krotto, (b) from Margaret to a friend, Fokke Cruetzberg, of Ottawa days and, finally, (c) from Fokke to Harry at the telescope, the experimental results arrived just in time to allow the detection of HC_7N in the interstellar medium (15). Synthesis of the cyanopoly-yne having $n = 4$ proved to be experimentally

challenging, but Takeshi Oka was able to extrapolate along the series $\text{H}(\text{C}\equiv\text{C})_n\text{--C}\equiv\text{N}$ ($n = 1, 2$ and 3) to predict with remarkable accuracy the spectroscopic constants for $n = 4$ and thereby to observe a rotational transition of HC_9N in space (16), although it is yet to be observed terrestrially.

In his Tilden Lecture (26), Harry speculated that chains of carbon atoms such as HC_n (*i.e.* without the cyano group) should also be detectable in the interstellar medium. So it was that as 1985 approached, Harry and his Sussex colleagues John Nixon and David Walton had not only synthesized a large number of small, reactive or unstable molecules containing B, S, P, or Se, and characterized them spectroscopically but also, stimulated by his work with David Walton on cyanopolyynes, Harry had turned his thoughts to the possibility of detecting long chains of carbon atoms in the interstellar medium as a way of trying to understand interstellar chemistry. He speculated in particular about the role of red-giant carbon stars in producing such carbon atom chains.

UNIVERSITY OF SUSSEX 1985-1996: C_{60} , FULLERENES AND THE NOBEL PRIZE

Louis Pasteur said (Pasteur 1854) ‘*Dans les champs de l’observation le hasard ne favorise que les esprits prepares.*’ often translated as ‘In the field of observation, fortune favours the prepared mind.’ Readers may judge from the following account whether this statement is appropriate to the discovery of buckminsterfullerene, C_{60} . Harry published in 1992 an excellent, discursive, personal account in *Angewandte Chemie* (47) from which the intensity and excitement surrounding the discovery is almost tangible. Inevitably, the description set out below relies for its facts on the *Angewandte Chemie* article and also on a similar account given in Harry’s Nobel Prize Lecture (61), although some of the detail of the discovery has necessarily been omitted.

Visits to Rice University 1984 and 1985

We have seen that Harry Kroto was already thinking about the possible role of long chains of linked carbon atoms in connection with the chemistry in the interstellar medium. On a visit to his friend and colleague Robert Curl at Rice University, Houston, Texas in 1984, Harry learned that Richard Smalley (also at Rice) had developed a laser-ablation source attached to a mass spectrometer by means of which it was possible to observe spectra of refractory materials. For example, Smalley had used this instrument to entrain in a pulse of helium gas the plasma produced when a laser impinges on solid silicon di-carbide SiC_2 , sweep the pulse of gas (after ionization) into the time-of-flight mass spectrometer, and record the visible spectrum of SiC_2 (Michalopoulos *et al.* 1984). Harry saw immediately that by using this technique it should be possible to vaporize graphite and examine the products to see whether long chains of carbon atoms were produced.

It took eighteen months to persuade Smalley to provide enough time on the instrument to try the experiment and Harry was determined to be there when it was carried out. He travelled to Houston in late August 1985, using money borrowed from Margaret, his wife, to pay his air fare. Only a few days were scheduled for the experiments, which began on 1 September, with Smalley's student Jim Heath and Sean O'Brien operating the instrument.

By varying the helium pressure and the distance the helium-entrained pulse travels to the mass spectrometer, they manipulated the clustering conditions, and thereby found that the peak in the spectrum corresponding in mass to sixty carbon atoms (see Figure 6 for a print of an early mass spectrum annotated by Harry) was more intense than other C_n peaks and could be further enhanced..

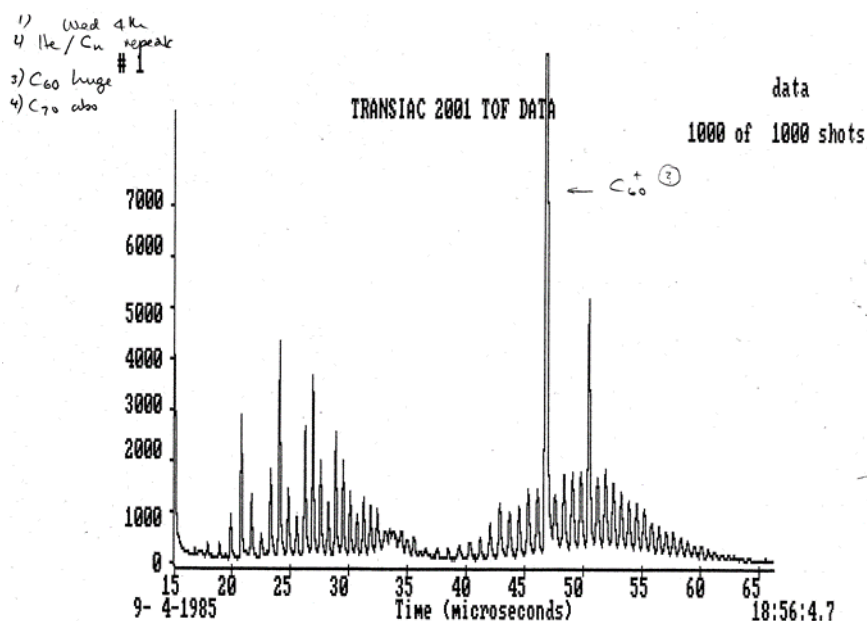


Figure 6 The mass spectrum of laser-ablated graphite recorded on 4 September 1985 using the spectrometer at Rice University. The annotations are in Harry Kroto's handwriting. After optimization of the clustering conditions, the peaks at C_{60}^+ and C_{70}^+ are several times greater in intensity than those of their nearest neighbours, even this early in the experiment. (reproduced from ref. 47 with permission).

Such an interesting result brought an extension to the time allowed for the graphite experiments and this was used to refine the conditions to optimise the intensity of the C_{60} signal. The result was astounding, as may be seen by the spectrum in Figure 6, which shows that not only was the C_{60} peak many times stronger than those adjacent to it, but that C_{70} was also special in that respect. Evidently C_{60} must be

more stable and/or formed more readily than other C_n . There followed a period of intense speculation among Curl, Kroto, Smalley and the students about what endows C_{60} with its special properties. What could be its geometry? A consensus grew in favour of a closed, spheroidal structure, which thereby avoided the need for dangling (unsatisfied and therefore reactive) bonds. Harry had vivid memories of the linked hexagons from which Buckminster Fuller's geodesic domes at EXPO 67 in Montreal were constructed. He also recalled the polyhedral star-dome he had constructed for his children years before, now languishing in a cupboard at home in Sussex. He discussed this at lunch with Curl on Monday 9 September and recalled cutting out pentagons as well as hexagons when making the star dome. Should he call his wife to get her to count the vertices (he suspected there might be sixty)? Eventually, for reasons of time difference he decided not to. Smalley obtained a book about Buckminster Fuller's geodesic domes from the Rice University Library.

At a dinner for the team in a Mexican restaurant on the evening of 9 September, all the evidence was reviewed again. Everyone agreed with a spheroidal geometry. Geodesic domes were discussed. Harry recounted once more the properties of the star-dome: its spheroidal shape and his recollection of hexagonal and pentagonal faces. The next morning, Smalley appeared with a paper model, made during the night, based on the star-dome characteristics and constructed from 20 hexagonal and 16 pentagonal faces. It had sixty identical vertices, each occupied by a carbon atom. It was so beautiful and so simple that they knew it must be correct. It transpired that its shape was known to mathematicians as a truncated icosahedron and was familiar to most people as the shape of a soccer ball, with its pattern of hexagons and pentagons (see Figure 7). Strangely, but unknown to Harry at that time, the experimental discovery of C_{60} had been preceded by the remarkable speculation of David Jones, a scientific journalist writing as *Daedalus* in the *New Scientist* in 1966 (Jones, 1966), that balloons composed of linked carbon atoms might exist. Moreover, in 1970, Osawa had proposed that a molecule C_{60} having a truncated icosahedron geometry could exist (Osawa 1970).

Harry delayed departure from Houston for a further day to participate in the writing of the now-famous, short paper submitted to *Nature* (29) and received only 13 days after the first experiment on 1 September. According to Web-of Science, as of 31 December 2016, this paper has been cited 10,000 times.

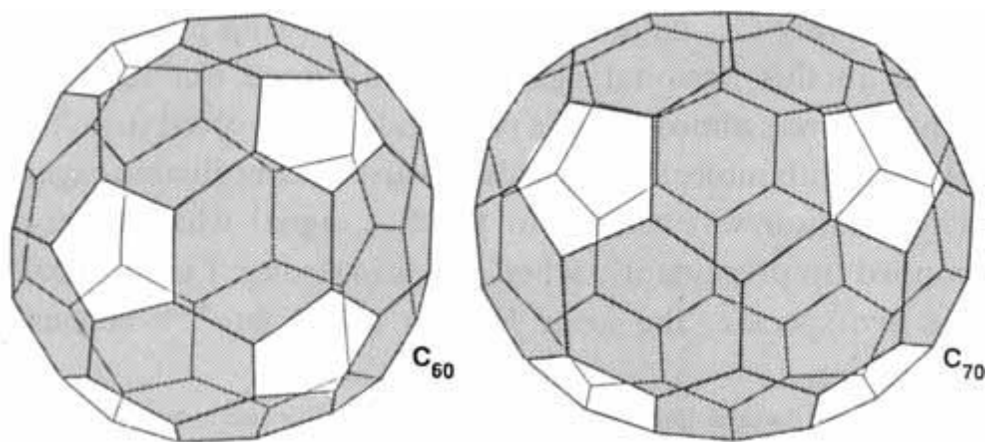


Figure 7 The proposed geometries of C_{60} (a truncated icosahedron with a carbon atom at each apex; all C atoms equivalent) and C_{70} (formed by inserting a ring of 10 carbon atoms between the two hemispherical halves of C_{60}). (Reproduced from ref. 47 with permission)

As beautiful and simple as their explanation might be, it was an uncomfortable fact that the experimental identification of C_{60} relied on the enhanced intensity of a single peak at 720 u in the mass spectrum of ablated graphite. Moreover, the enhanced intensity of the C_{70} mass peak also required explanation. Smalley proposed that this cage could be constructed from two hemispherical C_{30} halves of C_{60} by inserting a ring of 10 additional C atoms between them. (See Figure 7). Many papers followed in the next few years, discussing especially other possible closed C_n structures. One notable piece of experimental evidence was the successful encapsulation of a lanthanum atom within C_{60} .⁽³⁰⁾ In 1987 Harry published an important paper⁽³²⁾ in which he enunciated a set of empirical geodesic and chemical rules for predicting which clusters C_n would exhibit closed, hollow carbon cages of enhanced stability relative to near-neighbours. Prominent among these rules were (a) that according to Euler's Law (learned from the Daedalus article (Jones, 1966)), a sheet composed only of hexagons cannot close, the insertion of 12 pentagons being necessary for closure and (b) that structures in which each pentagonal ring is completely surrounded by hexagonal rings (*i.e.* that the pentagons are isolated from each other—the celebrated *Isolated Pentagon Rule*) are of special stability. All 12 pentagonal rings in C_{60} are completely isolated from each other and C_{60} satisfies the other rules enunciated in (32). Therefore C_{60} was assigned the optimum stability. The next cluster to satisfy the *Isolated Pentagon Rule* and to exhibit the necessary 12 pentagons was C_{70} , thus neatly explaining the dominance of the C_{60} and C_{70} mass spectral peaks in the products of laser-ablation of graphite. Harry also predicted, on the basis of his rules, closed-cage structures and enhanced stability relative to near-neighbours for those C_n for which $n = 24, 28, 32, 36$ and 50 , but these necessarily have some contiguous pentagons and are therefore predicted to be of lower stability.

So the circumstantial evidence grew, and the more it grew, the greater became Harry's confidence that he and his Rice colleagues were correct. But chemists like to have a macroscopic sample of a substance in their hands and characterize it spectroscopically (usually by the NMR and infrared techniques—the mass spectrum was already available) and Harry was no exception. The infrared spectrum was readily predicted to consist of 4 fundamental vibrational bands and, since all carbon atoms were equivalent, the ^{13}C -nmr spectrum should consist of a single line, so spectroscopic characterization of C_{60} should be straight forward. The problem was how to produce a macroscopic sample. This was not achieved until September 1990 and the five years between the discovery of C_{60} in 1985 and its characterisation *via* a macroscopic quantity were stressful and, in some respects, lonely.

A macroscopic sample of C_{60} in 1990

Harry was convinced that it was impracticable to produce a macroscopic sample of C_{60} by the laser-ablation approach. An interest that he and the group at Rice had developed in the possible role of C_{60} in soot formation (31) led, eventually and indirectly, to a way of producing much larger quantities of C_{60} . An electron micrograph of carbon micro-particles published in 1980 (Iijima 1980) appeared to show a set of concentric, quasi-icosahedral, giant fullerene-like shells, very similar in appearance to models of giant fullerenes, such as C_{540} , constructed by Harry's research student Ken McKay. This stimulated Harry to initiate an electron microscopy project to examine the relationship between C_{60} and soot formation. The approach was to strike a carbon arc in helium gas inside a bell-jar evaporator and examine whether C_{60} accompanied the production of the round carbon micro-particles as the helium pressure was increased. They did indeed detect carbon micro-particles by electron microscopy, but the project soon foundered because Harry had assumed that only a very small quantity of C_{60} would result, the detection of which would require a very sensitive quadrupole mass spectrometer. The money for the quadrupole mass spectrometer was not forthcoming, C_{60} was not detected and the project was placed in abeyance.

In September 1989, Harry learned, from a friend, of a conference paper (Krätschmer *et al.* 1990 a) which reported the infrared spectrum of a film of arc-deposited carbon. The spectrum showed four absorption bands at wavenumbers consistent with those predicted for C_{60} . Their apparatus was similar to bell-jar arrangement used by McKay. Harry immediately removed the McKay apparatus from storage and asked research student Jonathan Hare and undergraduate project student Amit Sarkar to repeat the experiment. They eventually (after various equipment problems and generous advice from Krätschmer) found conditions under which the infrared spectrum could be consistently observed. The implication was that the deposit must contain about 1% of C_{60} , although Harry found this difficult to believe. A mass spectrum of the soot taken on 27 July 1990 showed a decent C_{60} signal, but equipment failure precluded repetition of the experiment. On Friday, 3 August 1990, Jonathan Hare optimistically added benzene to a

sample of bell-jar soot and left it to stand for the weekend. On Monday morning, he noted a reddish solution above the solid. During that week he prepared more extract, evaporated the solution down to a few drops, but could detect no C_{60} signal in a mass spectrum that was run on the evaporated solution on Thursday, 9 August.

The next morning (Friday, 10 August) Harry received a telephone call from the journal *Nature* asking him to referee a paper submitted by the Krätschmer/Huffman group. He agreed and the manuscript was faxed to him immediately. It described the sublimation of C_{60} from arc-deposited carbon, the dissolution of the sublimate in benzene to give a red solution, and formation of crystals from the solution. The properties of the crystals, established by X-ray and electron diffraction, were just as expected for C_{60} .

To his great credit, Harry submitted his report to *Nature* the same day, congratulating the authors and recommending publication without delay (Krätschmer *et al.* 1990b). The fact that Harry did not isolate the first macroscopic sample of C_{60} , even though he had Jonathan Hare's red solution on his desk, was an enormous disappointment, but all was not lost. The Krätschmer/Huffman paper for *Nature* reported neither of the two methods of characterization beloved of organic chemists, namely, the mass spectrum and nmr spectrum. Clearly, to record these spectra was a matter of urgency. At this point Harry sought the help of a colleague at Sussex, the organic chemist Roger Taylor, whose input was crucial in two respects. First, he advised how to vaporize the red extract from a fast-atom bombardment matrix and thereby obtain its mass



Figure 8. Pure samples of C_{60} (magenta) and C_{70} (red) in benzene solution and the team that carried out their isolation and characterization. Left to right, front row: Harry Kroto, Roger Taylor and David Walton. Back row: Ala'a Abdul Sada and Jonathan Hare. (Copyright Margaret Kroto)

spectrum. This spectrum showed the presence of not only C_{60} , but also C_{70} and indeed other fullerenes C_n , where n is an even number. Secondly, Taylor isolated pure samples of C_{60} and C_{70} by preparative gas chromatography. The solutions of pure C_{60} and pure C_{70} in benzene were magenta and an intense red, respectively (See Figure 8).. The ^{13}C nmr spectra of pure samples of C_{60} and C_{70} dissolved in benzene were then obtained (34). As predicted, C_{60} exhibited just a single transition, while C_{70} showed four peaks having the intensity ratio of 2:1:2:1 in order of increasing chemical shift, a confirmatory signature.

Thus, the two fullerenes were fully characterized, no one could possibly doubt the discovery, and all remaining anxiety vanished. Harry was knighted for services to Chemistry in January 1996. Curl, Kroto and Smalley were awarded the 1996 Nobel Prize for Chemistry (see Figure 9) ‘for their discovery of the fullerenes.’



Figure 9 Harry relaxing (with medal) in Stockholm City Hall immediately following the Nobel Prize award ceremony. (Copyright Margaret Kroto).

Fullerene Chemistry in the 1990–1996 period

Following the publication of (34) in 1990, there was an explosive growth in both experimental and theoretical studies of the chemistry and physics of the fullerenes. For example, Harry published about 100 articles between 1990 and the award of the Nobel Prize in 1996. Some reported the infrared (35), Raman (36) and ultra-violet spectra (37) of C_{60} and C_{70} , while others investigated the circular dichroism (38) and neutron scattering characteristics (39) of C_{60} fullerene. Many articles were concerned with the chemistry

of C₆₀, including its fluorination (40), bromination (41), hydrogenation (42), and chlorination (49). Other chemistry involved the formation of C₆₀Ph₁₂ by aromatic substitution (43), the preparation of C₆₀(Ferrocene)₂ (48), the hydroboration of C₆₀ (53), the intercalation of P₄ into C₆₀ (54), the reaction of C₇₀ with benzyne (55), the preparation of cyclopentadienyl derivatives of C₆₀ (51), and so on. The chemistry was conducted almost entirely in collaboration with Sussex colleagues Roger Taylor and David Walton, with significant input from Jonathan Hare. Of the approximately 100 papers that emerged from the Kroto group from 1990-1996, Taylor and Walton were co-authors of the majority of them. Other articles published in that period describe the search for, and characterization of, other C_n ($n \neq 60$ or 70) closed-cage fullerenes, including the isomers of C₇₈ (46), the ground-state geometry of C₈₄ (44), and the ¹³C nmr spectra of C₇₆, C₇₈ and C₈₄ (50). An investigation of the hydrogenation of C₇₆, C₇₈ and C₈₄ with zinc/hydrochloric acid yielded hydrogenated clusters, but with some evidence of cage degradation (59). The concepts of stability domains and strain relief originally invoked in connection with C₂₈ were refined and applied to other small members of the fullerene family in an attempt to predict stability among their derivatives (52). The role of smaller clusters in space was also considered (56). There was speculation (45) about the existence of circumstellar and interstellar fullerenes and their role as carriers for the Diffuse Interstellar Bands (DIB), as first suggested in the original *Nature* paper of 1985 (29). Papers published towards the end of the 1990-1996 period heralded a change of direction in the Sussex research. For example, two articles published in *Carbon* in 1995, entitled ‘Hemi-toroidal networks of carbon nanotubes.’ (57) and ‘Nanotubes from vapor-grown carbon fibers’ (58) and one entitled ‘Nanoscale encapsulation of molybdenum carbide in carbon clusters’ in *Chemistry of Materials* in 1996 (60), indicate a move into materials aspects of carbon nanotube/fullerene research.

The growth of activity in research involving the fullerenes in the period 1990-1996 was not restricted to the Sussex group. Smalley and colleagues at Rice University also carried out much research in the area, for example, metals interacting with smaller fullerenes (Gao *et al.* 1993), but with the main focus shifting later to the recently-discovered, single-walled carbon nanotubes (Lou *et al.* 1995). There were also contributions from theoreticians. Many consisted of high-level calculations on single isomers, but the more ambitious often involved the discovery of rules for making predictions of stability among closed-cage fullerenes. As early as 1986, the Stone-Wales transformation was proposed as a hypothetical mechanism for the interconversion of fullerene isomers (Stone & Wales 1986). The Leapfrog Principle (Fowler & Steer 1987) predicts pseudo-spherical carbon clusters C_n, with $n = 60 + 6k$ and k equal either to zero or to any integer greater than one and having closed electronic shells. The Principle predicts the symmetries of the bonding orbitals of these ‘leapfrog’ clusters. The spiral conjecture (Manolopoulos *et al.* 1991) for fullerenes states that the surface of every fullerene may be unwound in at least one continuous spiral strip sharing five- and six-membered rings. Assignment of higher fullerenes (Diederich

and Whetten, 1992) used predicted ^{13}C NMR spectra from the spiral algorithm, which also gave clues to formation mechanisms (44). These are but a few of the contributions of theoreticians.

An important postscript to the Nobel Prize: C_{60} and the diffuse interstellar bands

The diffuse interstellar bands (DIBs) have been a challenge to astronomers, physicists and chemists ever since their first observation (Heber M. L, 1922). Mary Lea Heber observed a set of absorption lines produced when starlight from reddened stars passes through interstellar molecular clouds. Harry suggested in 1987 (very soon after the discovery of C_{60} in 1985) that C_{60}^+ could be the origin of at least some of the DIBs (33). His arguments were based on the remarkable stability of the C_{60} molecule, which was known to be formed in, and to survive in, the plasma produced when graphite is ablated by a laser. Harry's reasoning was that in starlight the C_{60} molecule would become ionized to give the cation C_{60}^+ . There the matter rested for some years until 1993 when John Maier and co-workers investigated (at Harry's suggestion) the spectra of C_{60}^+ molecules in isolation in solid neon or argon matrices (Fulara et al., 1993).

It was later suggested (Folng and Ehrenfreund, 1994) that two new DIBs, recently observed at 9577 Å and 9632 Å, might arise from C_{60}^+ , based on their proximity to those of similar wavelength observed by Fulara *et al.* in the solid matrices. The suggestion could not be confirmed, however, because of uncertainty introduced by matrix-induced wavelength shifts. Gas-phase measurements were required. Eventually, these were supplied in 2015, also by the Maier group, *via* an experiment in which C_{60}^+ was confined in a cryogenic trap by helium gas and its spectrum recorded at a temperature of 5.8 K, not far from that of the interstellar medium (Campbell *et al.* 2015). The two new DIBs at 9577 Å and 9632 Å were thereby positively identified, with an almost exact match in wavelength and linewidth with two absorption bands of gaseous C_{60}^+ . They also confirmed that two much weaker DIBs at 9366 Å and 9419 Å also arose from C_{60}^+ .

Harry was of course delighted that his friend John Maier had been successful, especially in view of an interview (<https://www.youtube.com/watch?v=TV2NzD16vv0>) on the BBC Television programme 'Horizon' in which the interviewer said (in connection with Harry's prediction about C_{60}^+ and the DIBs): 'But others have said that they are nothing like a match for the Diffuse Interstellar Bands'. Harry smiled and replied: 'They're wrong!' This exchange illustrates very well Harry's self-belief and scientific courage.

Research at Sussex moves in the direction of carbon nanotube-based materials (1996-2004)

As already noted, there were signs in his research output in 1995/6 that Harry Kroto's research focus was changing to include the study of materials and in particular the opportunities offered by the discovery of carbon nanotubes. From 1997 until 2016, Harry published a total of approximately 160 articles. Although some of these continued with investigations of the chemical and physical properties of the fullerenes, there is an increasing emphasis on carbon nanotubes, nanowires, and metal organic frameworks, the last being the most recent.

Carbon nanotubes appear to have been discovered independently by several groups over a long period of time. They can be found in the soot produced by the discharge of a carbon arc, while Smalley and co-workers (Guo *et al.* 1995) used a laser ablation method to generate them. There are now many methods of macroscopic scale production. Carbon nanotubes are fullerenes in the sense that they are composed of carbon atoms linked together in hexagons and appear like a rolled-up hexagonal mesh. The tubes have diameters $\sim 10^{-9}$ m (hence the name nanotubes) and can have lengths many millions of times their diameter. They can be single-walled or multi-walled. They have many remarkable properties, including high electrical and thermal conductivity along the tube axis, high tensile strength, and, as a further example, the ability to encapsulate metals.

During the period 1995 to 2004, the Kroto research group at the University of Sussex, in collaboration with others, published in excess of 100 research articles concerned with carbon nanotubes, nanotubes composed of other materials, and various related nanostructures. David Walton, Jonathan Hare and Nicole Grobert were co-authors of many of these. Only a relatively small number of the most-cited examples will be mentioned here. The group synthesized carbon nanotubes via the catalytic pyrolysis of acetylene (62), and reported a method for the controlled production of aligned carbon nanotube bundles (63). They also synthesized and measured the properties of nanowires composed of Fe (64) or Sn-Pb (65) sheathed in carbon nanotubes. They synthesized carbon nanotubes coated with WS_2 (72), but also produced nanotubes composed only of WS_2 (67) and measured their shockwave resistance (73). The Sussex group additionally showed how to promote the growth of niobium disulfide (NbS_2) nanotubes by means of a carbon nanotube template (70). The electronic field emission characteristics of NbS_2 nanotubes were tested after discovering a method of making large scale samples (74). Routes to molybdenum disulfide (MoS_2) nanotubes were devised (68), as well as methods to generate mixed-phase $\text{W}_x\text{Mo}_y\text{C}_z\text{S}_2$ nanotubes (69) and silicon-based nanostructures (66). Alloy nanowires, composed of Invar metal inside carbon nanotubes, were an interesting development (71). Research into the chemistry and photophysics of the fullerenes also continued

during the period, although the number of published article decreased significantly compared with the period 1990-1996.

The move to Florida State University at Tallahassee

In 2004, Harry became 65 years old, retired from his position at the University of Sussex, and accepted an offer from the Florida State University (Tallahassee) (FSU) to take up the Francis Eppes Chair of Chemistry. One reason for the move was to ensure the continued funding of his research, but he was also interested because FSU were keen to explore new ways of using the internet for educational outreach. This led to GEOSET (see below). Another advantage of the move was that Margaret Kroto gave up her job and became the full-time organizer of Harry's extensive travel plans and indeed frequently accompanied him. The translation to FSU led to only a short hiatus in research output. His research on nanotubes continued to flourish, with important discoveries such as the *in situ* nucleation of carbon nanotubes by injection of carbon atoms into metal particles (76), the production of a flexible, cross-linked, multi-walled carbon nanotube paper capable of sensing hydrogen at low concentration (79), and polyurea-functionalised multi-walled carbon nanotubes (75). There was a resurgence of fundamental work on the fullerenes in collaboration with FSU colleagues Paul Dunk and Alan Marshall, including seminal papers on the closed network growth of fullerenes (80), the bottom-up formation of mono-metallofullerenes as directed by charge transfer (81) (both in *Nature Communications*), and formation of the smallest stable fullerene $M@C_{28}$ ($M = \text{Ti, Zr or U}$) grown from carbon vapour (82). He also made contributions in the area of metal-organic framework systems (MOFs) in collaboration with Anthony Cheetham (FRS, 1994) and with FSU colleagues Naresh Dalal and Prashant Jain (77,78). One article on MOFs has the intriguing title: Electric Control of Magnetization and Interplay between Orbital Ordering and Ferroelectricity in a Multiferroic Metal Organic Framework (77).



Figure 10, Harry and Margaret in Florida in 2015. (Copyright Margaret Kroto).

Harry and Margaret (see Figure 10) were forced to return permanently to their home in Lewes, East Sussex in the Autumn of 2015, somewhat earlier than they had planned, owing to the onset of the motor neurone disease (also known in the USA as either amyotrophic lateral sclerosis or Lou Gehrig's disease), which progressed rapidly and from the complications of which Harry died on April 30, 2016.

Other science-based activities: Outreach, The Vega Trust and Geoset

Harry was undoubtedly charismatic. He was relaxed in the company of children and was certainly not pompous or diffident, as some scientists can be. He was also blessed with a voice/accent that was easy to listen to, but at the same time commanded attention. He was therefore well-equipped to pursue successfully his long-standing interest in educational outreach. Harry enjoyed giving talks to school children from early in his career. No doubt demand for his talks increased after the discovery of C_{60} , and the fame endowed by a Nobel Prize does no harm when it comes to attracting an audience. His famous C_{60} 'Buckyball' workshops were popular not only because of their hands-on, model-making content, but also because of his gift for engaging children's attention. They were as successful with primary school children as they were with secondary school pupils. The mutual enjoyment felt during these kinds of interactions is evident from the photograph in Figure 11 taken at a 'Bucky ball' workshop in Malaysia



Figure 11. Mutual enjoyment of a 'Buckyball' Workshop in Malaysia. (Copyright Margaret Kroto).

Harry felt that the Nobel Prize heightened his long-held sense of responsibility to promote the public understanding of science, especially among children and young adults. In his later years, he was in very great demand to give research lectures and travelled extensively for that purpose. (He once told me that he received about one invitation per day involving international travel). He adapted the conference travel to suit his outreach interests, however. He would certainly attend a conference and give a research lecture, but he would also fit in one or more children's workshops during the same trip. His 'buckyball' workshops are well-known throughout the world, and have been held in many countries, including Australia, Japan, Italy, Malaysia, Germany, Mexico, Sweden, Colombia, Chile, Spain, USA and India. After moving to Florida State University, he used to invite groups of children from elementary schools into the Chemistry Department for the same purpose. He also did many children's workshops via the internet, some of which are available here: <http://vega.org.uk/video/subseries/29>. One of the 'Buckyball' workshops took place at Manchester United Football Club, where two first team players at the time, Diego Forlan and John O'Shea, were recruited to help. This workshop was also recorded and is available as a video on the website. As a result of his special relationship with the University of Sheffield and Bolton School, he participated in regular workshops in both cities, those in Sheffield being organized by the University's Outreach Team and its Kroto Research Institute, but he always responded positively (his hectic schedule permitting) to requests from where ever they came.

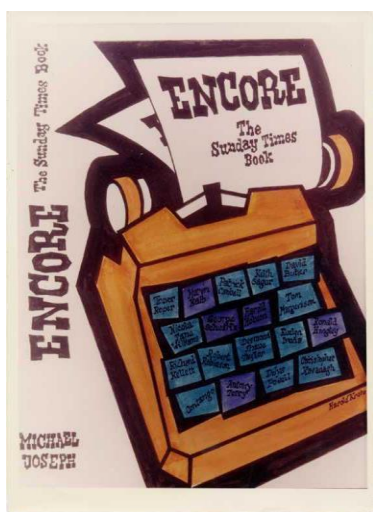
Others aspects of the public understanding of science were also important to him. In 1994, together with ex-BBC producer Patrick Reams he created the Vega Science Trust which provided a broadcast platform for the science, technology, engineering and mathematics (STEM) communities, so enabling them to communicate on all aspects of their fields of expertise using exciting internet opportunities. The Vega Trust website (<http://www.vega.org.uk/>) is an amazing and priceless resource that will appeal to anyone with even a passing interest in science. It is not only already of great historical significance, but it also communicates very effectively the excitement engendered by all aspects of contemporary science. It makes accessible, for example, video recordings of famous scientists discussing their research. Included in these are lectures by Richard Feynman, the outstanding science communicator of his era, interviews with Max Perutz, John Walker, Walter Kohn, Fred Sanger, Sherwood Rowland and Harry himself (all Nobel Prize winners) and many more. Also available from the Vega Trust website are videos of the following types: BBC documentaries, Master Classes in science, some devoted to art and science, those provided as an educational resource, those intended to help with science careers, and, of course, recordings of Harry's 'Buckyball' workshop. The Vega website ceased to be updated in 2012, but it remains an important resource. Harry's Presidency of the Royal Society of Chemistry from 2002 to 2004 was a role which

provided him with an appropriate platform, and many further opportunities, to contribute to the public understanding of Chemistry..

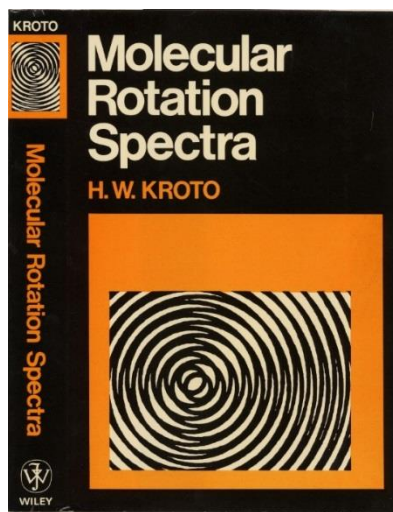
Two years after the move to Florida State University at Tallahassee in 2004, Harry set up GEOSET (Global Educational Outreach for Science Engineering and Technology), for which he raised the funds. He was helped on the technical aspects by Steve Acquah, who later became the Director of the project. GEOSET is a web-based organization, introduced to provide a free resource of educational material. The main website provides a database gateway that links the many institutions that contribute to GEOSET with the local GEOSET site at FSU. The purpose of GEOSET is best described in Harry's own words (<http://www.kroto.info/geoset/>): *'Whereas almost all educational programmes focus on a particular student cohort, the GEOSET initiative's paradigm shifting strategy is to turn the focus of the educational process round by 180 degrees to target our best teachers and capture Specific Educational Objects or Concept Modules which they have devised to infuse real enthusiasm and passion for intellectual knowledge in students. Although the GEOSET site streams many outstanding lectures and courses, as indicated above, the primary aim is the creation of an easily accessed cache of specific Teaching Tricks Of The Trade i.e. TTOTTs which outstanding educators have found by experience work. Until now the educational genius of a teacher is in general lost when he or she retires unless a student, who also becomes an educator, remembers it and uses it in class. GEOSET (and its more inclusive sister GEOSTEAM encompassing the arts and mathematics now in preparation) gives our teachers a measure of immortality previously unavailable.'*

Other non-science based interests

Outside science and education, Harry's main intellectual passion was for graphic art. As a graduate



(a)



(b)

Figure 12 (a) Harry's winning design for the *Sunday Times* Book jacket competition in 1962 (when a graduate student) and (b) his design for the dust jacket of the Wiley edition of his monograph *Molecular Rotation Spectra*. (Reproduced with permission of (a)and (b).....)

student at Sheffield, he entered the *Sunday Times* book-jacket design competition and won first prize in the amateur section. The winning design is shown in Figure 12, which also displays his design for the dust jacket of the first edition of his monograph *Molecular Rotation Spectra* published in 1975.

Other examples of his graphic art can be seen on his website (<http://www.kroto.info/graphics/>). His sporting passion was tennis, a game that he played with colleagues at Sussex until he was relatively old.

Not surprisingly, in view of the treatment of his parents in Germany and the UK between 1937 and the end of the Second World War, Harry was a passionate member of Amnesty International. In fact, for many years the only tie I ever saw him wear carried the familiar 'candle wrapped in barbed wire' logo of that organization. He was opposed to all religion, for which he said he had never seen any reason. He spent a considerable amount of time when in Florida opposing the teaching of Creationism in High Schools as an alternative to teaching of the theory of evolution. In his autobiographical piece on the Nobel Prize website (http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1996/kroto-bio.html), he sets out in detail his reasons for being an atheist and a humanist. On his website (<http://www.kroto.info/where-i-stand/>) may be found his views on scientific, political and religious topics, set down in a forthright manner.

APPOINTMENTS, PRIZES, HONOURS

Appointments

1967–2004 University of Sussex (Brighton): Tutorial Fellow, Lecturer 1968, Reader 1977, Professor 1985–2005, Royal Society Research Professor (1991–2001)

2004 –2015 Florida State University, Francis Eppes Professor of Chemistry

Membership of Societies/National Academies

- 1990 Fellow of the Royal Society.
- 2002-4 President of the Royal Society of Chemistry (2002-2004),
- 1993 Mexican Academy of Science; Member Academia Europaea.
- 1997 Hon. Foreign Member Korean Academy of Science and Technology.
- 1998 Hon. Fellow of the Royal Microscopical Society.
- 1998 Hon. Fellow of the Royal Society of Edinburgh.
- 2000 Hon. Fellow of the Royal Society of Chemistry.
- 200? Foreign Member Finnish Academy of Sciences.
- 2005 Academy of Sciences (Torino)
- 2007 Foreign Associate of the National Academy of Sciences, United States.

Medals and Prizes

- 1982 Tilden Lectureship and Medal (Royal Society of Chemistry).
- 1992 International Prize for New Materials (American Physical Society) (shared with Robert Curl and Richard Smalley).
- 1992 Italgas Prize for Innovation in Chemistry 1992.
- 1993 Longstaff Medal (Royal Society of Chemistry).
- 1994 Hewlett Packard Europhysics Prize (shared with Wolfgang Krätschmer, Don Huffman and Richard Smalley)
- 1994 Moët Hennessy Louis Vuitton LVMH. "Science pour l'Art".
- 1996 Knighthood
- 1996 Nobel Prize for Chemistry for 1996 (shared with Robert Curl and Richard Smalley)
- 1997 Medal for Achievement in Carbon Science for 1997 (American Carbon Society) (shared with Robert Curl and Richard Smalley).

- 1998 Dalton Medal (Manchester Lit and Phil).
- 1999 Blackett Lectureship (Royal Society).
- 2000 Ioannes Marcus Marci Medal for Spectroscopy (Prague),
- 2001 Faraday Award and Lecture (Royal Society)
- 200? Erasmus Medal of Academia Europaea.
- 2002 Copley Medal (Royal Society).
- 2005 Order of Cherubini (Torino).
- 2008 Kavli Lecturer (Royal Society).

Honorary Doctorates

1. Université Libre de Bruxelles (Belgium)
2. University of Stockholm (Sweden)
3. University of Limburg (Belgium)
4. University of Sheffield (UK)
5. University of Kingston (UK)
6. University of Sussex (UK)
7. University of Helsinki (Finland)
8. University of Nottingham (UK)
9. Yokohama City University (Japan)
10. University of Sheffield-Hallam (UK)
11. University of Aberdeen (Scotland)
12. University of Leicester (UK)
13. University of Aveiro (Portugal)
14. University of Bielefeld (Germany)

15. University of Hull (UK)
16. Manchester Metropolitan University (UK)
17. Hong Kong City University (HK China)
18. Gustavus Adolphus College (Minnesota, US)
19. University College London (UK)
20. University of Patras (Greece)
21. University of Dalhousie (Halifax, NovaScotia, Canada)
22. University of Strathclyde (Scotland)
23. University of Manchester (UK)
24. Kraków Mining University (Poland)
25. University of Durham (UK)
26. Queens University Belfast (NI)
27. University of Surrey (UK)
28. Politecnico di Torino (Italy)
29. University of Chemical Technology – Beijing (China)
30. University of Liverpool (UK)
31. Florida Southern College (US)
32. Keio University (Japan)
33. University of Chiba (Japan)
34. University of Bolton (UK)
35. University of Hartford (US)
36. University of Tel Aviv (Israel)
37. University of Poitiers (France)
38. Universidad Complutense de Madrid

39. Naresuan University (Thailand)
40. Vietnam National University (Hanoi)
41. University of Edinburgh(UK)
42. University of Primorska (Slovenia)

Honorary degrees returned in protest after closure of Chemistry Departments or courses

1. Hertfordshire University (UK)
2. University of Exeter (UK)

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